Paper ID: 99397
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32nd IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS (B4)
Interactive Presentations - 32nd IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS (IP)

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PROPOSED CUBESAT SYSTEM FOR AUTONOMOUS STRUCTURAL HEALTH MONITORING: INTEGRATION OF EDGE COMPUTING AND MACHINE LEARNING FOR ANOMALY DETECTION AND ORBITAL SAFETY

Abstract

The increasing number of satellites in low Earth orbit (LEO)—projected to exceed 100,000 operational units by 2030—and the rising risk of collisions with space debris highlighted the necessity for advanced, real-time Structural Health Monitoring (SHM) solutions. Traditional ground-based monitoring exhibited high latency and limited observation windows, emphasizing the demand for onboard anomaly detection. In response, this work proposed a CubeSat-based SHM system, designed for a 1U platform, to autonomously detect micrometeoroid impacts, material fatigue, and thermal stress while ensuring precise orbital positioning.

The system integrated high-resolution multispectral cameras with edge computing-enabled machine learning algorithms, processing images onboard to minimize latency and reduce reliance on ground-based analysis. By leveraging object-oriented classification and spatial-spectral data fusion, the approach achieved significantly higher damage detection accuracy compared to conventional methods, as validated through recent orbital testing aboard the Nanoracks platform on the International Space Station (ISS). Furthermore, onboard processing reduced data transmission delays, aligning with emerging edge computing frameworks for satellites.

A critical aspect of the design was the optimization of imaging capabilities for the 1U CubeSat. Evaluations determined the resolution required to reliably visualize the satellite and detect potential damage—such as perforations, solar cell degradation, stuck antennas or panels, and protective coating erosion—while maintaining efficient intersatellite communication speeds. The CubeSat's modular architecture ensured scalability for constellation deployments and compliance with the ISO 24113 standard (space debris mitigation), facilitating integration into existing satellite networks and safe operations. Additionally, the system incorporated predictive maintenance functionalities, forecasting component degradation using historical telemetry data, a crucial feature for long-duration missions.

Building on recent advances in hyperspectral imaging and edge-AI optimization, the proposed system offered a cost-effective solution for academic, commercial, and governmental applications, including studies on spacecraft longevity, planetary exploration, and satellite servicing.